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A FRACTURE VALLEY SYSTEM.

THE correspondence between the drainage system in the region north of the Yellowstone National Park and the system of fractures traversing the rocks is so striking that there can be little doubt of a causal relationship between them. The studies of de la Bèche in England, of d'Omalius and Daubrée in France, of Kjerulf and Brögger in Norway, and recently of Hobbs in Connecticut have demonstrated that in certain localities there is the closest correspondence between the valleys or drainage system and the fractures in the underlying rocks recognized as faults or joints. And Daubrée in his classic work *Études synthétiques de géologie expérimentale*, has shown how a more or less rectangular system of nearly parallel joints may be produced by torsional stress as well as by compression.

The almost universal application by geologists in former times of the idea of the controlling influence of fractures on drainage, and the exaggeration of the importance of faulting in this connection, coupled with the evident independence of many drainage courses from faulting, and their obvious dependence on other factors, led to a revulsion on the part of modern physiographers from the views of earlier geologists to such an extent that the influence of rock fractures on drainage courses has been minimized, if not altogether neglected, in recent times.

One reason for the revulsion from the idea of fracture drainage systems is to be found undoubtedly in the emphasis formerly laid on the conception of faulting as an essential element in the problem. This was introduced in the term "fault valleys," (*vallées de failles*) of d'Omalius, and has been memorialized in the vignette on the title-page of the *Annual Report of the United States Geological Survey*. That such valleys occur is well known, but that they form a small fraction of the whole is beyond dispute.

It is to be noted, however, that the demonstrations of Daubrée deal chiefly with joints or fractures (*cassures*), rather than with faults (*failles*), the two being but different phases of the same phenomenon, fracturing; one, a result of small or imperceptible displacement; the other, of profound, or at least notable, dislocation. The torsional experiments of Daubrée produced more or less rectangular systems of nearly parallel fractures, some of which might be called joints, and others faults. The studies of Becker,[1] Van Hise,[2] and Hoskins[3] have established the laws and frequency of parallel and of conjugate joints (*systèmes conjugués* of Daubrée) and the phenomena have become familiar to all geologists who have worked in regions of well exposed disturbed rocks.

The phenomena are in part as follows: There are faults in more or less parallel lines through wide extents of territory intersected by faults at various angles often nearly 90°.

A dominant or major fault is frequently accompanied by parallel fractures of minor degree, which are in some cases close to the dominant fault, in other cases at considerable distances from it.

Faulting is accompanied in parts of its course by crushing and brecciation of the wall rocks; in other parts the sides of the fault are closely pressed together without evidences of brecciation. Further, there are portions of a fissure plane where the walls are not closely compressed, but may be actually open.

Planes of fracture and fissuring are often lines of special decomposition of the rock material, and are for this reason less resistant than the neighboring rocks.

From these facts it is evident that the course of drainage, in following lines of least resistance, may cut its way along fault lines where they are in brecciated, loosely aggregated, or decomposed rocks, but may leave the faults in places where unbroken rocks are closely compressed. Moreover, streams may find less obstacle in cutting unfractured softer rock than in removing fractured harder material.

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[1] GEO. F. BECKER, *Monograph* III, *U. S. Geological Survey* (Washington 1882), pp. 156–87; *Bulletin of the Geological Society of America*, Vol. IV (1893), pp. 41–75; and *Transactions of the American Institute of Mining Engineers*, Vol. XXIV (1894), pp. 130–38.

[2] C. R. VAN HISE, *Sixteenth Annual Report*, *U. S. Geological Survey* (Washington, 1896), pp, 633–78.

[3] L. M. HOSKINS, *ibid.*, pp. 845–74.

Numerous parallel joints would aid erosion, if it were once located along a dominant fissure, by permitting the falling in of the sides of the drainage channels. Consequently, it is reasonable to expect that planes of fracture will in some cases become lines of drainage and pronounced erosion, while in other cases they may be disregarded by streams.

It is also known to every field worker that dislocations in large areas of massive rocks are easily overlooked, and are often difficult to determine when suspected; and further that minor fractures are generally neglected in geological field work. It follows from this that much evidence that may exist connecting the location of drainage with rock fractures has not been collected, and much that might be sought, by the very nature of the problem, may not be found, because the bottom of a valley is usually filled with loose material that conceals the rocks through which the valley has been cut.

A study of a mountainous region such as that lying north of the Yellowstone National Park must convince one that fracture systems have had more influence on the location of drainage than is ordinarily supposed, or than can be actually demonstrated, perhaps, by the evidence obtainable from the region in its present condition of rock exposure.

With regard to the presentation which follows, it is to be remarked that the problem of a possible fracture drainage system was not in mind when the writer was in the field, and no special search was made for evidence bearing on the question. The argument offered is based on such observations on the structure of the region as were made in the field by Mr. W. H. Weed and the writer, and on the drainage features of the map prepared by the topographers.

The topographic map which is reproduced is a reduction of that of the Livingston Quadrangle, Folio 1 of the *Geologic Atlas of the United States*. The geology of the district may be found in the folio. In this connection the map of the Three Forks Quadrangle Folio 24, and those of the Yellowstone National Park, Folio 30, should be studied.[1]

[1] U. S. Geological Survey, *Geologic Atlas of the United States*, Folio 1, Washington 1894; Folio 24 and Folio 30, 1896.

A simplified drainage map in which the drainage lines are somewhat straightened is given on the thin sheet, which is intended to be placed over the topographic map. The purpose of straightening the drainage lines is to present a simpler expression of the system, rendering the persistency of some of the directions more evident, and permitting the relationships of the various directions to be more easily noted. It does not follow that drainage channels would be more in accord with fracture systems if they were straighter. Fractures and faults are not necessarily straight. They are more often curved or crooked, as is the case with most of those observed in the region under discussion. The fault lines and dikes are printed in blue on the thin sheet. It is probable that the irregularities of direction in the drainage, as it is drawn on the topographic map, are more in accord with the fractures than the straightened lines traced on the drainage map. The value of the tracing is in the simpler expression of the system, serving the same purpose as a simplified statement of a highly complex set of relationships. It may be looked upon as a diagrammatic statement of the drainage system.

The region embraced by the map lies between the meridians 110° and 111°, and latitudes 45° and 46°. It is immediately north of the Yellowstone National Park, and contains the Snowy Range, the eastern slopes of the northern portion of the Gallatin Range, part of the Bridger Range, and the southern slopes of the Crazy Mountains. The Yellowstone River traverses the quadrangle from the south and southwest to the northeast, its tributaries intersecting the country in all directions.

A study of the topographic map reveals the angular character of much of the drainage system, and the prevalence of certain parallel and sub-parallel lines which appear in various streams and occur in quite diverse portions of their channels. Along parallel lines different streams may be flowing in opposite directions; one stream may be near its source, another near its mouth, having other portions of their channels trending in other directions. The persistency of these lines becomes more striking when the geological structure of the region is taken into account and it is observed that certain drainage lines traverse rocks of such diverse nature as gneiss and schist, volcanic tuff breccia and solid lava, limestones, sandstones, and shales.

The relation of some of these directions of drainage to known fracture planes will be pointed out. The dominant drainage lines in the southern three-quarters of the quadrangle trend about northeast-southwest and northwest-southeast, more nearly N. 30° E. and W. 30° N., the angle between them being approximately 90°. There are other systems of almost rectangular lines somewhat differently oriented, namely, north-south and east-west. These are well developed in the central eastern part of the quadrangle.

Let us consider these systems in some detail, commencing with the main drainage channel, that of the Yellowstone River. This enters the quadrangle on the south in a curiously zigzag channel, known as the Third Canyon, cut in crystalline schists. The longer zigzag lines run northwest, and the shorter are almost at right angles. The northwest direction is followed from Gardiner to Reese Creek in Cretaceous strata, is exchanged for a more northerly direction as far as Yankee Jim, where the northwest direction is followed through a narrow gorge into the open valley, where a right-angled turn is made to the northeast. From Reese Creek to the open valley the river traverses crystalline schists.

The dominant northwest line of the river just described is parallel to the most profound fault within the region; namely, that which threw the whole sedimentary series, including the Laramie Coal Measures, down below horizons of crystalline schists. It is a fault of more than 11,000 feet and probably is more than 16,000 feet. This fault appears to end abruptly at Cinnabar Creek, the principal throw being southeast of Reese Creek.

It is interesting to observe that the Yellowstone River in no place exactly follows the fault line as it is located on the present surface. But it is evident from the topography of the country south of the river and east of Gardiner that parallel fractures must exist on both sides of the fault line, and these must control the northwest direction of the tributary streams and the longer lines of the zigzag Third Canyon. These lines persist to the southeast within the boundary of the Yellowstone National Park, the fault itself being covered by younger volcanic lavas.

As already remarked, the great fault appears to end at Cinnabar Creek, but the Yellowstone River follows a line parallel to it through the gorge at Yankee Jim, and parallel lines of lesser drainage are plainly shown in the vicinity. Whether the fault actually ceases at Cinnabar Creek cannot be determined, because of the covering of volcanic rocks forming the surface of the mountainous country westward. Beyond these lavas, however, in a direct line a similarly profound fault is exposed in the Madison Range in the Three Forks Quadrangle. This was accompanied by a similar throw of the sedimentary strata south of the crystalline schists, and is in a direct line with the fault just described. The total length of the combined fault lines is over sixty miles.

Parallel to this great fault are several well defined ones of less extent, the largest lying north of Mill Creek Basin. Here there are two sub-parallel faults which unite in the head of the North Fork of Mill Creek. The dominant one of these has been traced from the Boulder Canyon westward to the Yellowstone Valley, a distance of twenty miles. The shorter fault has been traced for thirteen miles. They are not observed west of the Yellowstone Valley in the Gallatin Mountains because of the covering of volcanic lavas, but they appear again with the same characters in the Madison Range just west of the lavas, evidently passing beneath them. The western faults are exposed for twenty miles, and there can be no doubt of their persistence beneath the lavas. In this case the total length of the principal fault would be sixty-four miles.

In the bare gneisses two miles north of the fault line at the head of the North Fork of Mill Creek joint planes or small faults are clearly visible, parallel to the main fault and having a hade to the south, indicating normal faulting.

In other parts of the region there are faults parallel to those just described. A small one within the area of crystalline schists occurs in the southeast corner of the quadrangle, crossing

Slough Creek. It is exposed for a short distance only, being covered at both ends by volcanic rocks. A still smaller one was observed six miles farther north. These indicate the presence of fractures parallel to the profounder faults.

North of the body of crystalline schists a northwest fault exists in the valley of the East Boulder River; another is situated south of Livingston Peak; and two smaller faults occur between this mountain and Livingston. Two more are located just west of the Yellowstone River in this vicinity; and there is a short one northwest of Mount Ellis, in the central western margin of the quadrangle.

The presence of major fractures in a northwest-southeast direction being clearly established, the occurrence of parallel fractures of minor importance is rendered highly probable, some in fact, having been observed in the field.

Corresponding to these northwest-southeast fractures are the channels of many of the tributaries of Slough Creek, Buffalo Creek, and Hell Roaring Creek; the minor branches and the main channels of many of the streams flowing into the Yellowstone, as far as Livingston, notably those in the Gallatin Range. The most remarkable instance, which is a good example of a fault valley, is the valley of East Boulder River.

Returning to the consideration of the course of the Yellowstone River, it is seen that upon leaving Yankee Jim Canyon it flows at right angles through a broad valley in a northeasterly direction for forty miles. More strictly, the first twenty miles are about N. 30° E., the next sixteen miles being more northerly. From the mouth of Shields River beyond Livingston the course is south of east, nearly at right angles to its course at Livingston. This is followed by a right-angled bend at McAdows Canyon, after which the course is northeast to the edge of the quadrangle.

The broad valley of the Yellowstone between Yankee Jim Canyon and the Lower Canyon, which valley continues southwest up Tom Minor Creek, lies in the direction of a scarp fault forming the western flank of the Snowy Mountains. The summits of gneiss and schist at 11,000 and 10,000 feet from Emigrant

Peak to Mount Delano rise abruptly on the east side of the valley, while on the west there are the long sloping spurs of volcanic lavas overlying sedimentary strata in the northern part of the Gallatin Range. The location of this fault was not discovered in the field, as it is undoubtedly obscured by the valley deposits. It dies out abruptly before reaching the Lower Canyon, near Livingston, and is probably most profound north of the cross fault at Mill Creek.

This northeast direction is the same as that of two pronounced faults in the southwest corner of the quadrangle that enter it from the Yellowstone National Park. One lies in the drainage channel of Cinnabar Creek; the other is in the valley of Reese Creek. It is probable that a third fault parallel to these occurs in the valley of Gardiner River west of Mount Everts, but it has not been definitely located. These faults terminate in the great northwest fault in Yellowstone Valley south of Sheep Mountain.

The throw of the Cinnabar Creek fault is to the west, but the extent of the displacement is not determinable. It has been traced for a distance of eighteen miles. The Reese Creek fault is clearly recognizable east of Electric Peak, where the throw is to the east and the displacement more than 6,000 feet. It continues southward as a scarp fault along the east flank of the Gallatin Mountains in the Yellowstone Park. It is known for twenty miles, and disappears under lava. The throw of the fault west of Mount Everts is to the west.

A minor fault parallel to those just described occurs in the gneiss east of, and parallel to the channel of Hell Roaring Creek. Several northeast-southwest faults of slight extent have been noted north of the great body of crystalline schists. One is a short spur connected with the fault in the valley of the East Boulder River. Two are connected with the northwest-southeast faults southeast of Livingston, and another is south of Mount Ellis in the western part of the quadrangle. In each of these cases it is interesting to observe that there are conjugate faults at nearly right angles.

In the direction of the northeast-southwest fractures, besides the Yellowstone Valley and Cinnabar and Reese Creeks, which are definitely located on fault lines, there are the channels of Bear Gulch and Crevice Gulch, Hell Roaring and Slough Creeks, with tributaries to Boulder River and Mill Creek, and the upper portion of the West Boulder.

Another conjugate system of fractures is indicated by the rectangular drainage with lines almost north-south and east-west. The direction of the main Boulder River through its canyon is the same as that of several of its head branches, of Buffalo Creek to the south, and of several north-south drainages to the east. The east-west direction is found in tributaries of the Boulder River, in the North Fork of Mill Creek, and in a stream in line with this east of East Boulder plateau. In this case there is a fault nearly parallel to the North Fork of Mill Creek connected with the northwest-southeast system of faults. An east-west fault has also been observed by Mr. W. H. Emmons near Haystack Peak at the head of Boulder River. There can be little doubt that in this portion of the quadrangle there is a system of fractures in an east-west and north-south direction.

The sculpturing of the canyons of the Boulder and West Boulder, and of several to the east, seems to require the action of other agencies than those of ordinary erosion. These narrow canyons have been cut 3,000, 4,000, and 5,000 feet into gneiss and schist within a few miles of their heads, and their drainage basins seem quite inadequate to furnish sufficient water for so great and such deep erosion. It seems as though the rocks must have been rendered more susceptible to abrasion by being fractured or jointed.

A similarly placed system of drainage channels exists in the northwestern corner of the quadrangle west of Shields River and east and south of the Bridger Range, but no system of fractures or faults has been noted in this region.

The northeastern corner of the quadrangle is intersected by a distinctly rectangular system of drainage. The channels of the Yellowstone and Boulder Rivers, with the tributaries of the Shields River, have a northern trend nearly at right angles to those of Shields River and several creeks flowing southeast from the Crazy Mountains, and numerous small tributaries of the

Yellowstone and the Boulder Rivers. That these directions are parallel to existing fractures is shown by the trend of dikes of igneous rock that traverse this part of the country. A number of dikes occur in Crow Indian Reservation on the Boulder River. They trend northwest almost exactly parallel to the small streams in this vicinity. Two longer dikes occur on Gage Creek, trending in the same direction. In the valley of Shields River there are dikes having a northeast-southwest trend. The Crazy Mountains are filled with innumerable dikes radiating in all directions from the core of igneous rocks lying north of the Livingston quadrangle. That portion of the mountains within the limits of the map is traversed by dikes trending north-south in the middle of the group, on the east side trending east of south, and on the west side trending west of south, but not parallel to the drainage channels in the foothills. Apparently these fractures are immediately connected with the intrusive core of the mountains, and have not extended into the surrounding sedimentary strata for long distances. The system of fractures indicated by the drainage is probably more profound and was produced by deeper-seated forces.

There are dikes and lines of intrusive rocks parallel to neighboring drainage channels in the vicinity of Haystack Peak, Emigrant Peak, and at the west base of Sheep Mountain.

Besides the drainage that may have been controlled or initiated by fracture lines, there are within the area covered by the map excellent examples of channels that have followed softer rocks, where the minor topographic features of the country conform to the position and character of the sedimentary strata, and where fracture and faulting appear to have had no influence on the drainage. It is the larger valleys and dominant channels that exhibit the general relationship between drainage and fracture.

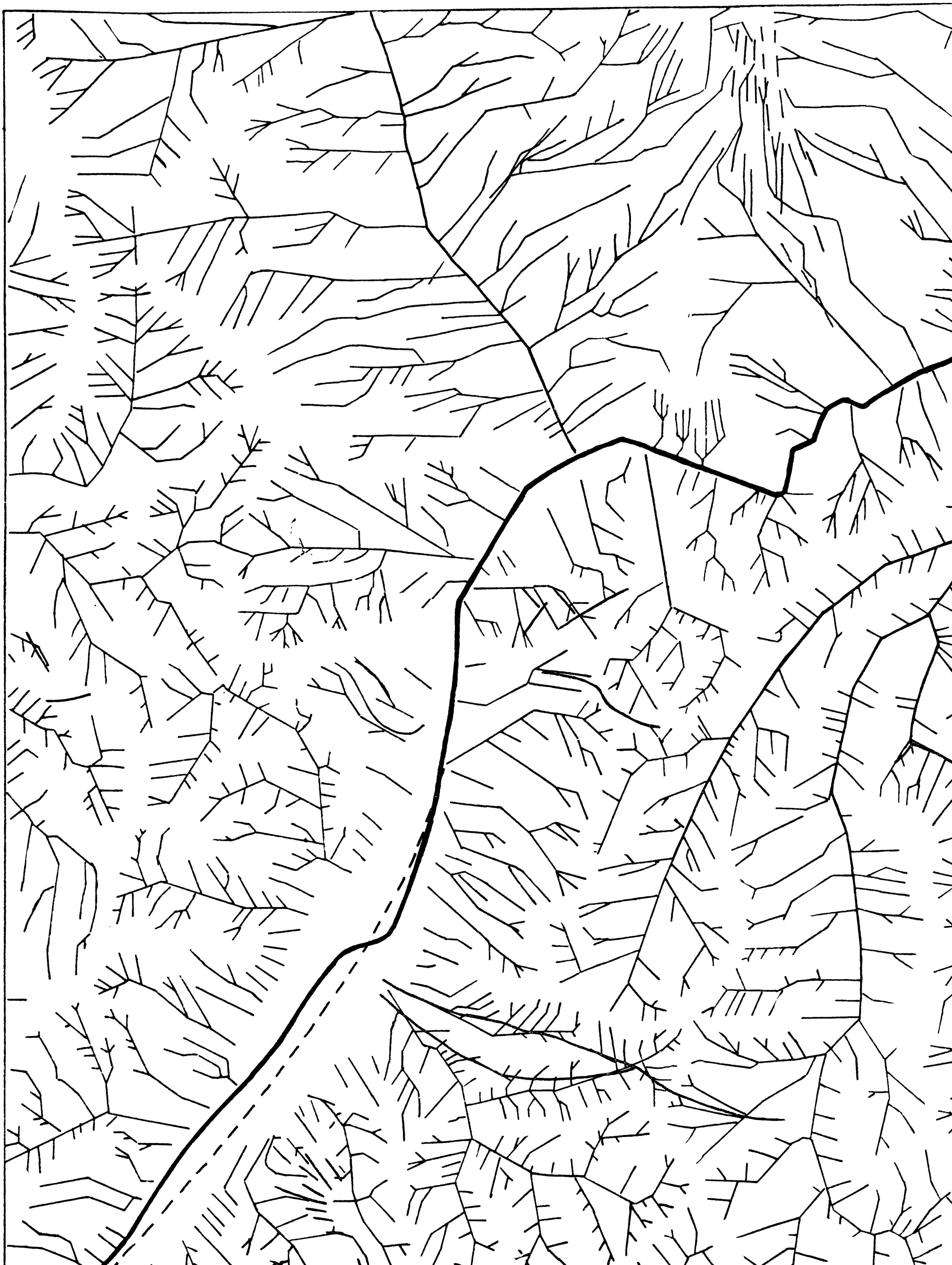
That the drainage system of this quadrangle is closely related to the structural features of the rock formations will not appear surprising when the geological history of the region since Laramie times is taken into account.

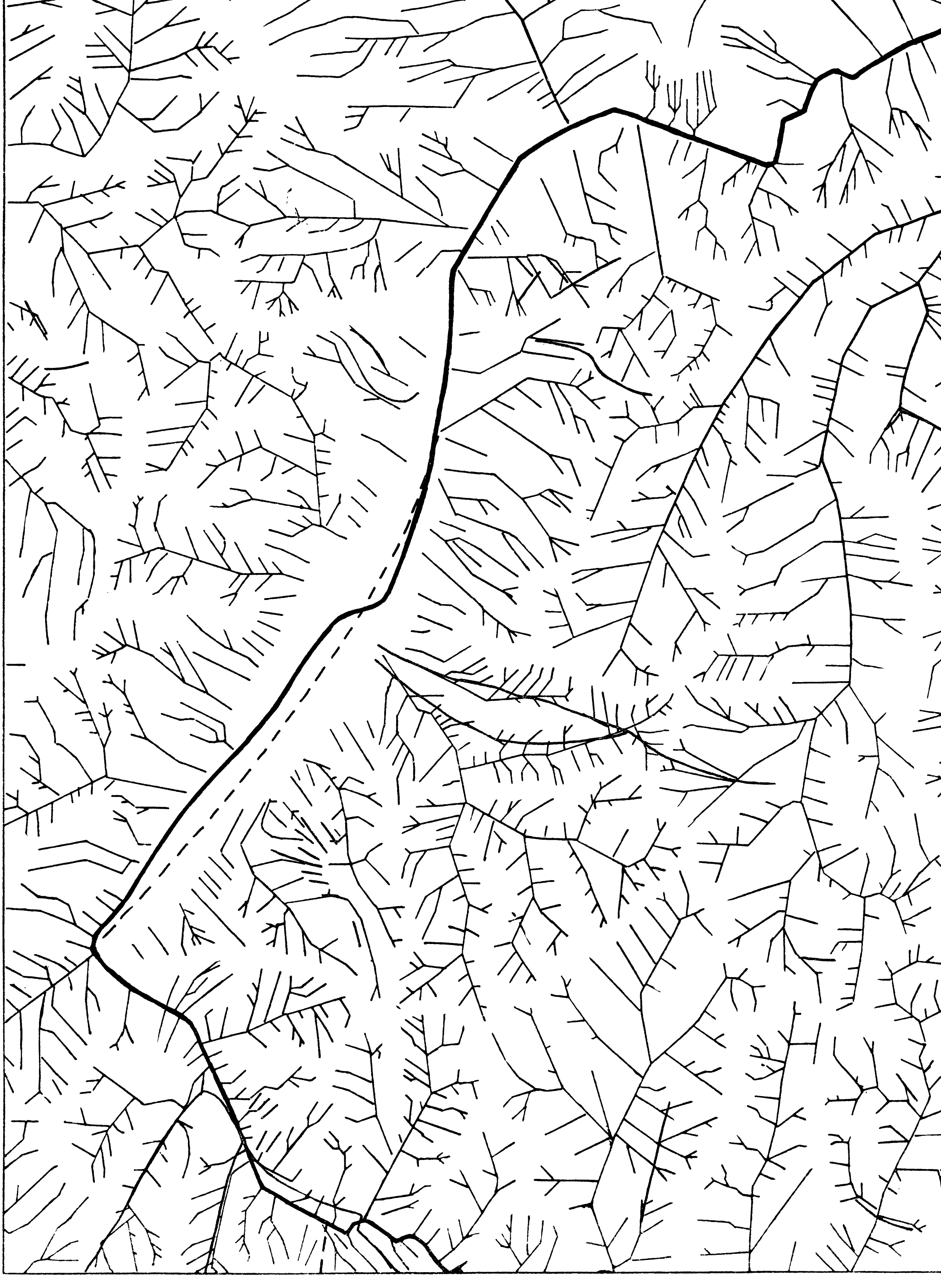
The dislocation of the crystalline schists and sedimentary strata that followed the deposition of the Laramie resulted from torsional shearing stresses of great magnitude, as is shown by the rapid variation in the amount of displacement along the planes of faulting. These fractures have occurred in nearly parallel planes, and also in a nearly rectangular system, and resulted in faults and joints.

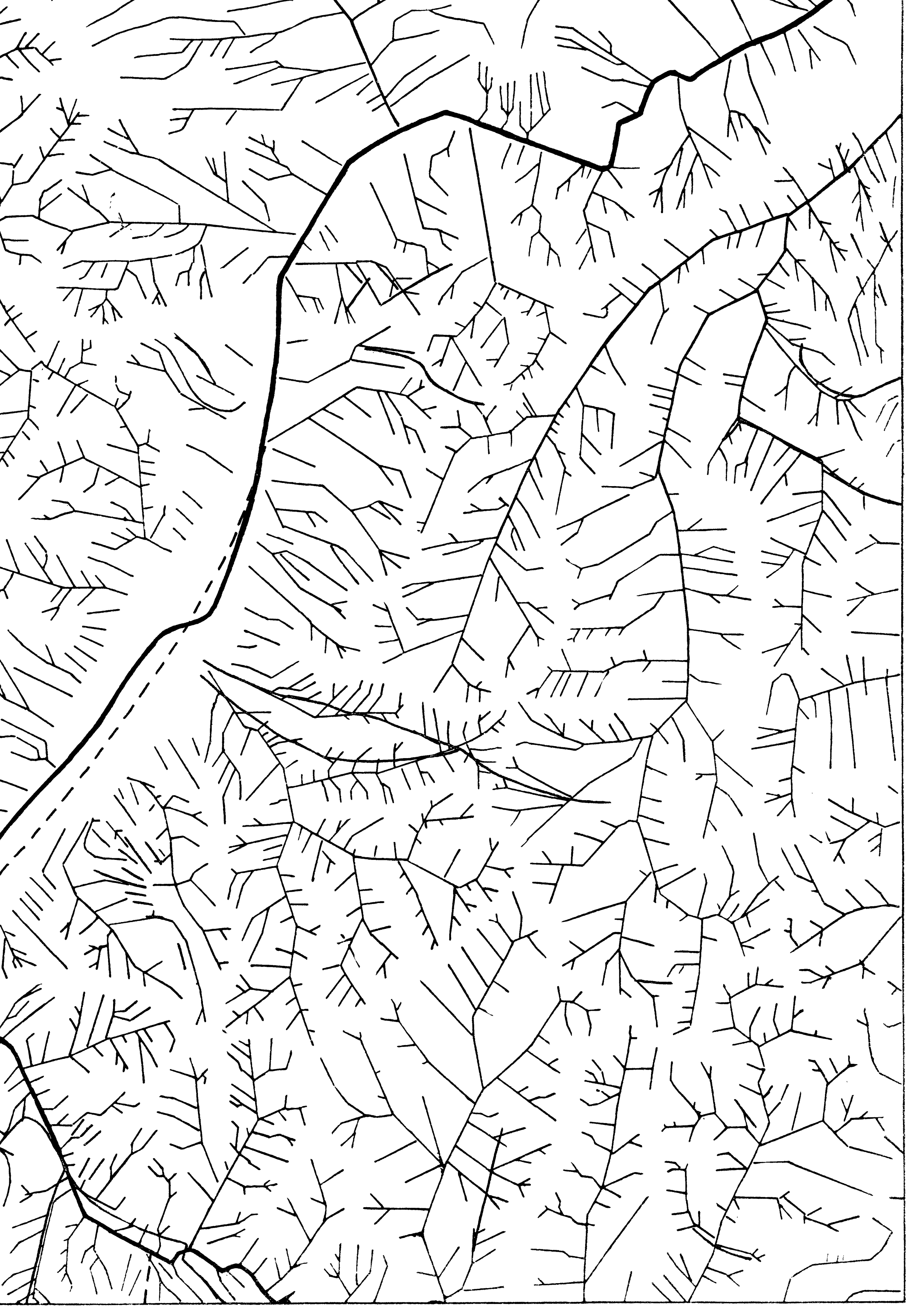
The fractured and dislocated rocks were eroded to a very great extent at a very early period. Thus from a large area the entire sedimentary covering, 10,000 feet or more in thickness, was removed from the underlying crystalline schist before Eocene times, and the surface of the country presented an irregular topography not greatly different in character from that of the present day. Upon an irregular surface of crystalline schists in the present valley of the Yellowstone River, just south of the Livingston quadrangle, there rest horizontal beds of Eocene volcanic tuff with ancient tree trunks in vertical position. Erosion has reduced the rocks in this vicinity to nearly the same surface at successive periods, as is shown by the occurrence of surface extrusive lavas of very different ages in close proximity. The direction of the drainage in this locality has undoubtedly shifted repeatedly during this long lapse of time.

Since volcanic activity commenced, fracturing and faulting have taken place at intervals through the Tertiary period. The profoundest faulting and erosion took place before Eocene times and the extravasation of Eocene tuffs. This was followed by great accumulations of Miocene tuffs and lavas, which were fractured and dislocated along the faults in Cinnabar and Reese Creeks, and elsewhere. These were greatly eroded in late Tertiary time before the eruptions of Pliocene rhyolite which has been faulted in its time.

In the faulting of the Electric Peak and Sepulchre Mountain blocks there was unquestionably a displacement along the line of the earliest northwest-southeast fault against which these blocks terminate proving a recurrence of fracturing and displacement along old lines of jointing and faulting. And while there is little or no evidence in this region that successive faulting has often taken place at widely remote geological periods along the same lines, it seems probable that profound jointing may establish







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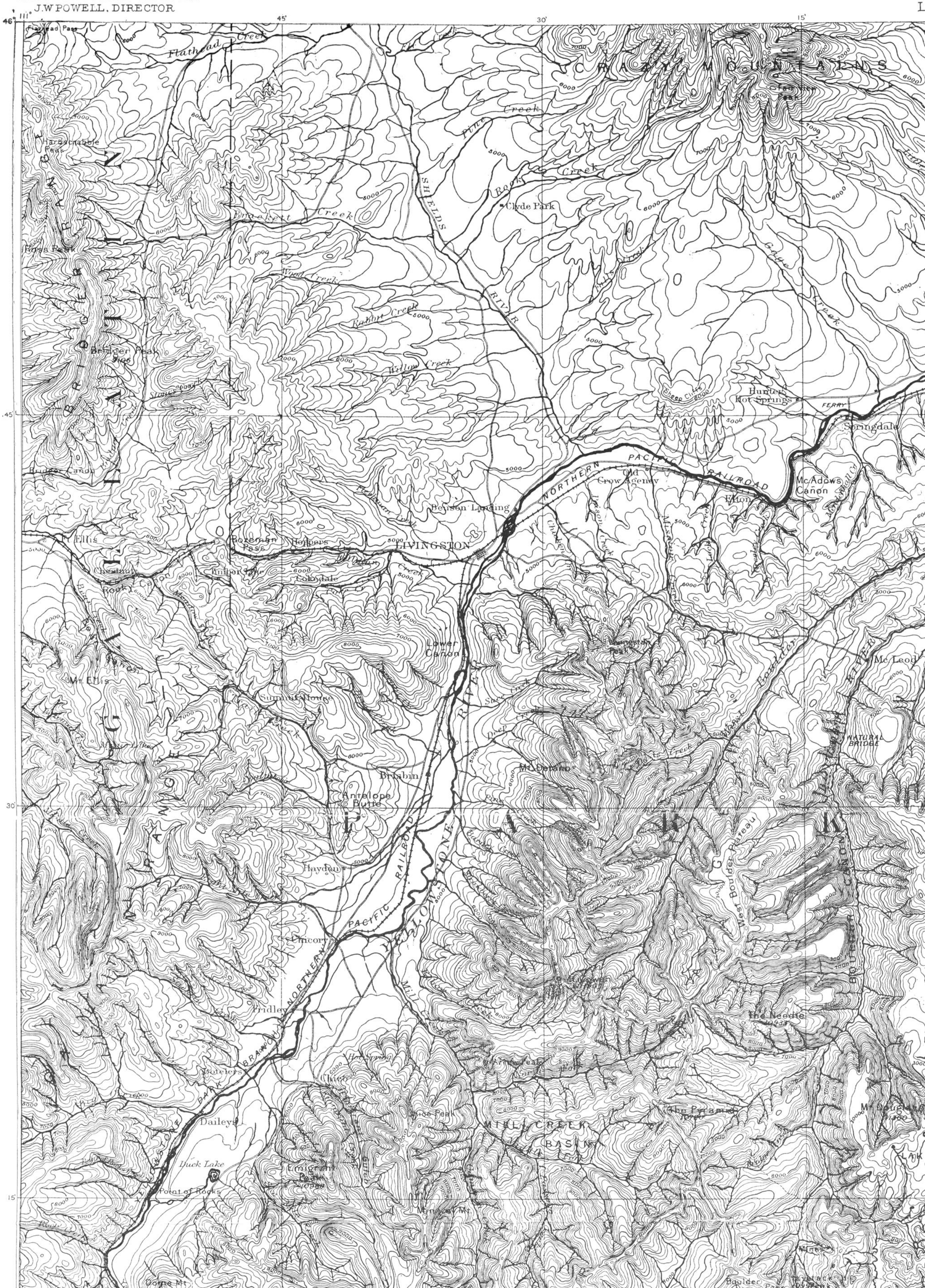

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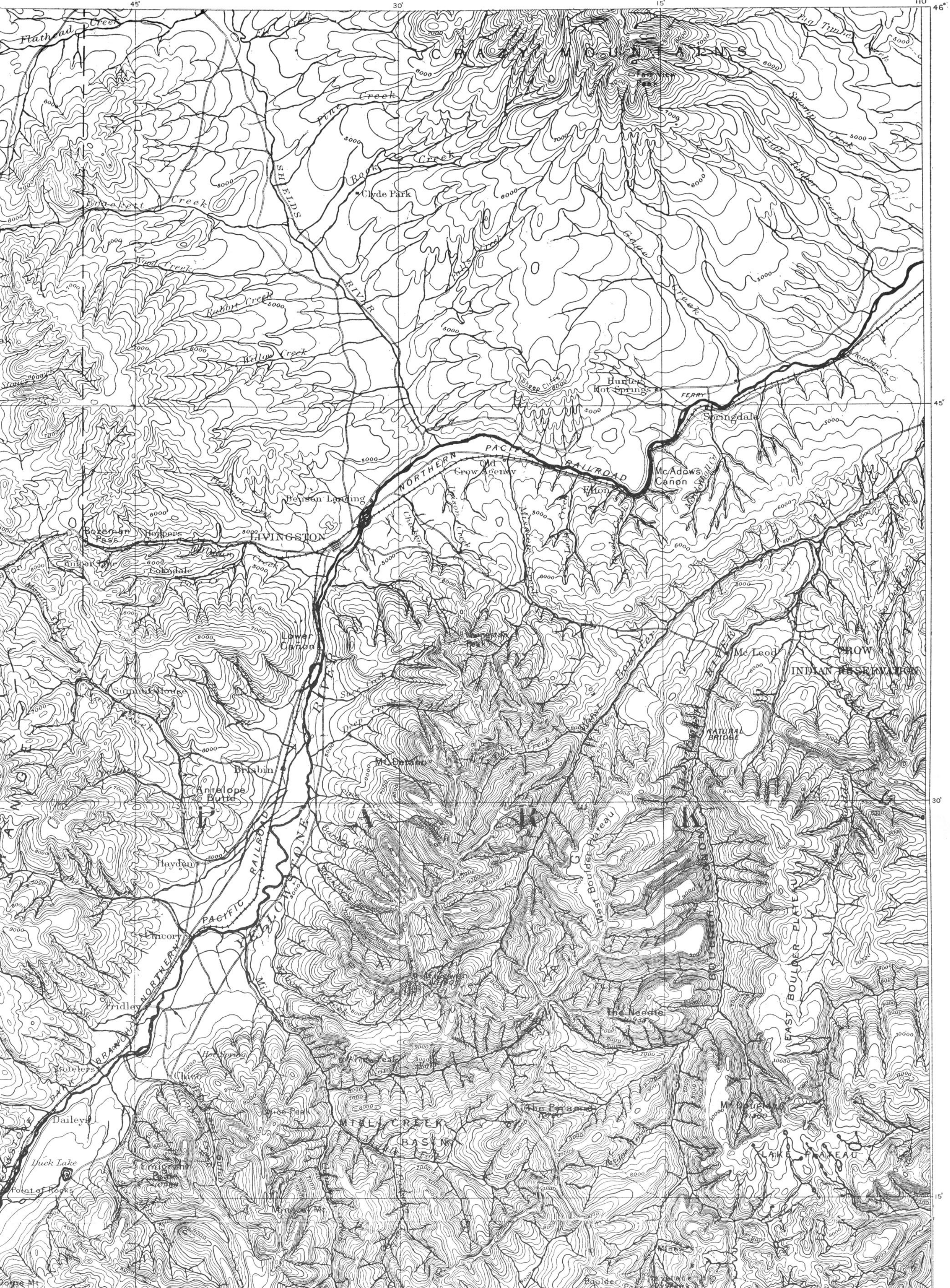

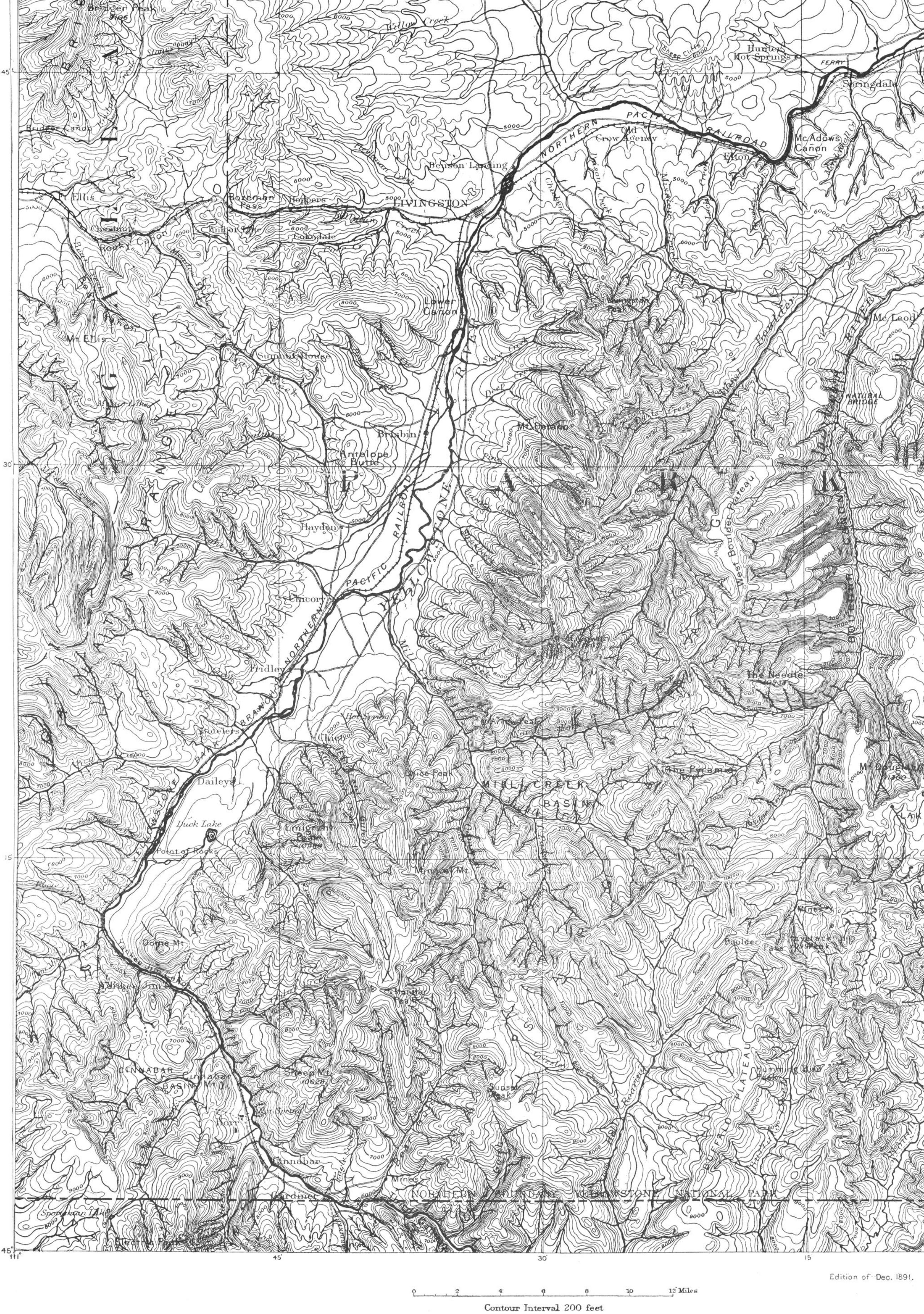

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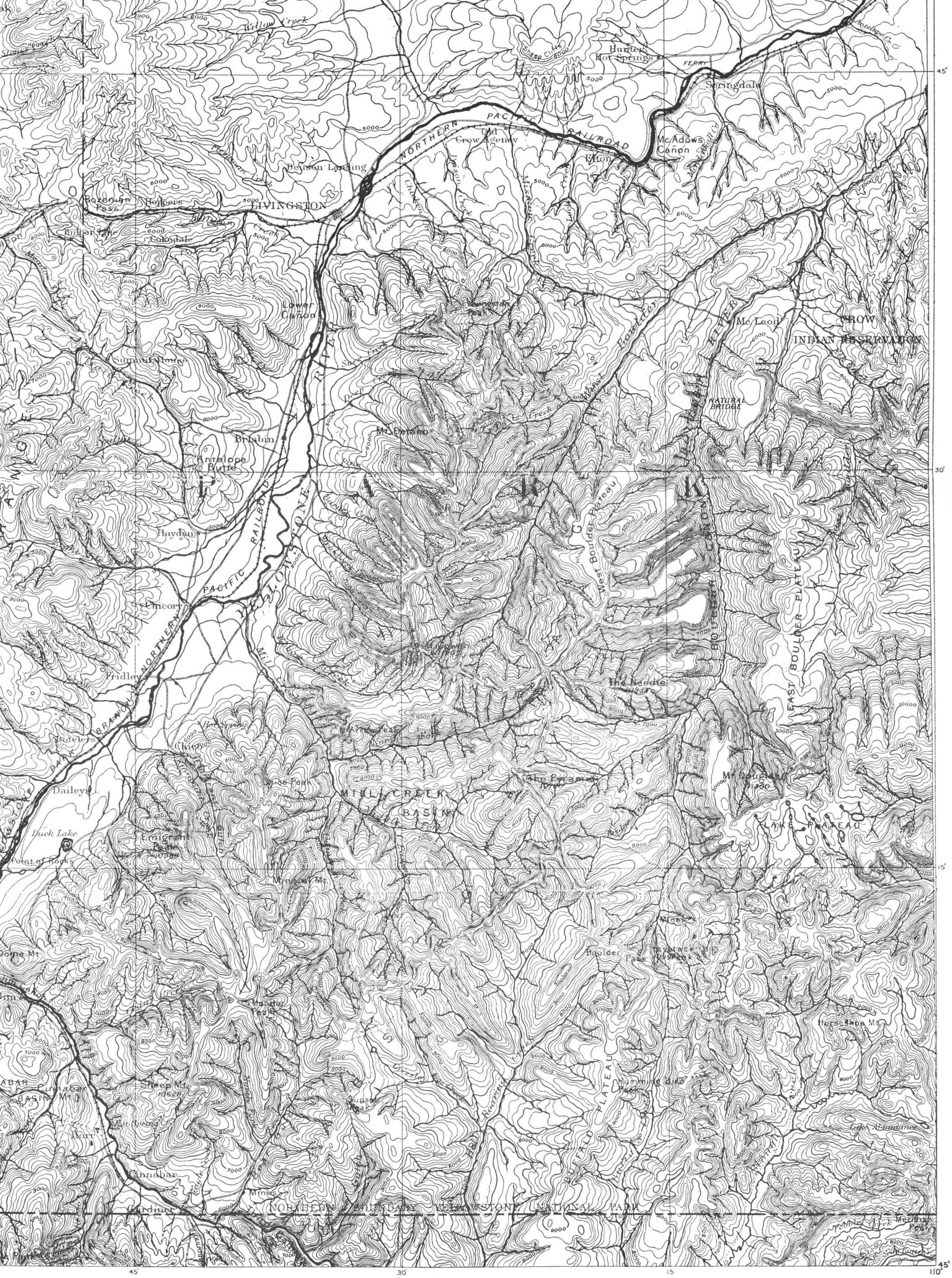

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planes of weakness along which subsequent movements of a minor character may take place affecting superimposed rocks, so that a system of Eocene, or even late Cretaceous, joints may be extended upward into overlying rocks in Miocene time provided similar dynamic action of a pronounced character occurs in both periods as it has in this region.

JOSEPH P. IDDINGS.